TITLE OF THE INVENTION
Thermal Spray Spherical Particles, and Sprayed Components

5   This invention relates to thermal spray spherical
particles of rare earth-containing compound useful for
thermal spraying on ceramics or a metal, and a sprayed
component.

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BACKGROUND OF THE INVENTION
From the past, plasma spraying and detonation spraying
techniques have been widely utilized for forming dense spray
coatings on surfaces of ceramic or a metal. In these
15   thermal spraying techniques, metal, metal oxide and the like
are often used as the spray powder.
More particularly, it is a common practice in the art
to thermally spray metal or metal oxide particles onto metal
or ceramic substrates to form a coating thereon for
20   imparting heat resistance, abrasion resistance and corrosion
resistance. The properties of the coating thus formed
depend on the spraying conditions as well as the properties
of powder particles to be sprayed.
The particle powders suitable for thermal spray
25   coatings typically include (1) a fused and ground powder
obtained by melting a starting material in an electric
furnace, cooling the melt for solidification, and
pulverizing the solid in a grinding machine into particles,
followed by classification for particle size adjustment; (2)
30   a sintered and ground powder obtained by firing a raw
material, and pulverizing the sintered material in a
grinding machine into particles, followed by classification
for particle size adjustment; and (3) a granulated powder
obtained by adding a raw material powder to an organic
35   binder to form a slurry, atomizing the slurry through a
spray drying granulator, and firing the particles,
optionally followed by classification for particle size

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adjustment. The starting material used in the preparation of these powders (1) to (3) is selected as appropriate and has been developed in accordance with the cost and the desired properties of the end spray coating.

5   While plasma processes are involved in the recent semiconductor fabrication art, rare earth-containing compounds have been developed as a wafer processing component in corrosive halide gases because they have high resistance to plasma.

10   When spray coatings are applied to components in semiconductor manufacturing apparatus, the spray coatings are required (a) to contain less impurity elements other than the predominant constituents and (b) to have a less irregular, smooth surface bearing less fines, which means to

15   suppress dusting during wafer processing. To meet these requirements, it becomes crucial how to control the properties of powder particles to be sprayed as well as the spraying conditions.

The thermal spray particles have to meet the

20   requirements that (i) they can be consistently fed without disintegration at a quantitative rate to the plasma or flame during spraying, (ii) they are fully melted during spraying (in plasma or flame) and (iii) they are highly pure. These requirements are quantitatively expressed by more than ten

25   physical parameters and elemental analysis data of particles.

Since the thermal spray particles are fed to the spray gun through a narrow flowpath such as a transportation tube, whether they can be consistently fed at a quantitative rate

30   is largely affected by the flow thereof among other physical parameters. However, the fused or sintered and ground powder resulting from method (1) or (2) has irregular shapes which lead to the drawback that the sprayed coating has large irregularities. Additionally, the fused and ground

35   powder has the other drawback that the content of impurities other than the constituent elements is high, and the

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sintered and ground powder has the other drawback that
impurities are often introduced in the grinding step.

Developed as a solution to these problems of the
ground powders was the granulated powder obtained by method
(3), that is, having the advantage of smooth flow due to the
spherical or nearly spherical shape of particles. An
additional advantage of the granulated powder is that a
relatively pure granulated powder can be readily prepared by
reducing impurities in the starting material.

However, a starting powder of a certain type can give
rise to the problems that particles of a shape dissimilar to
sphere are granulated therefrom and that the starting powder
sticks to granulated particles. An additional problem is
that a degradation of flow is incurred particularly when
particles have a small diameter.

When a coating is sprayed using the granulated powder,
the fines which have not been granulated (i.e., have been
carried from the starting powder) are incorporated in the
coating or stick to the surface of the coating. This causes
a substantial amount of dust to generate when the coated
component is used in semiconductor equipment or the like.

In order that particles of metal compound be thermally
sprayed, without dust generation, to form a coating having
improved bond strength, the particles must be completely
melted in the flame or plasma during the spraying step and
the supply of the feed particles must be precisely
controlled. Particularly when particles of rare earth-
containing compounds are used for thermal spraying, because
of their high melting point, they should preferably have a
smaller average particle size so that they may be completely
melted.

In the event where granulated powder is prepared using
a spray drying granulator, however, it is difficult to
selectively prepare a fraction of particles having a small
average particle size. Inevitably, particles having a
relatively large average particle size are concomitantly
produced. Such particles with a large average particle size

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have a large weight and are not completely melted when fed into the plasma flame so that they are incorporated in the sprayed coating as unmelted particles, which become one cause of incurring irregularities in the coating.

5   One approach for overcoming the above-mentioned problems is to reduce the particle size of the starting material for eventually holding down coating surface irregularities. This approach is undesirably accompanied by generation of fines, a degradation of flow and a difficulty
10   of precise metering. As a result, surface irregularities develop and the coating becomes less dense. Furthermore, the fines which stick to particle surfaces without being granulated are not introduced into the plasma flame during the spraying step and are thus kept unmelted so that they
15   are incorporated in or stick to the sprayed coating.

SUMMARY OF THE INVENTION

A first object of the invention is to provide thermal spray spherical particles which have a sufficient breaking strength to remain uncollapsed in the flame or plasma during
20   spraying.

A second object of the invention is to provide thermal spray, high purity particles of rare earth-containing compound which can be thermally sprayed to form a smooth, dense coating despite the high melting point of the rare
25   earth-containing compound, and without generation of fines.

A third object of the invention is to provide a smooth sprayed component having the particles spray coated on a substrate surface without concomitant sticking of fines.

30   In a first embodiment, the invention provides spherical particles for thermal spraying, consisting essentially of a rare earth(inclusive of yttrium)-containing compound and having a breaking strength of at least 10 MPa and an average particle diameter of 10 to 80 μm. Most
35   often, the rare earth-containing compound is a rare earth oxide, and more preferably the rare earth oxide is yttrium oxide or ytterbium oxide.

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Thermal spraying spherical particles consisting essentially of a rare earth(inclusive of yttrium)-containing compound having a breaking strength of at least 10 MPa and an average particle diameter of 10 to 80 μm are prepared by granulating rare earth(inclusive of yttrium)-containing compound (especially rare earth oxide) fines having a Fisher diameter of up to 0.6 μm into granules.

The thermal spray particles of rare earth-containing compound having a specific breaking strength and average particle diameter according to the first embodiment of the present invention do not collapse in the spraying flame or plasma and thus form a coating in which no unmelted fragments are incorporated or to which surface no unmelted fragments stick. Especially, by processing a starting oxide powder under predetermined conditions, thermal spray particles having the desired physical properties are produced.

In a second embodiment, the invention provides spherical particles for thermal spraying, consisting essentially of a rare earth-containing compound and having a bulk density of at least 1.0 g/cm^3, an aspect ratio of up to 2, and a cumulative volume of pores with a radius of up to 1 μm which is less than 0.5 cm^3/g.

The spherical particles have a particle size distribution in which a particle diameter D90, D50 and D10 corresponds to 90 vol%, 50 vol% and 10 vol% accumulation, respectively. Preferably D90 is up to 100 μm and the ratio of D50 to a Fisher diameter is up to 5. Also preferably, D10 is at least 5 μm, and a dispersion index is up to 0.6.

In a further embodiment, the invention provides a thermally sprayed component comprising a substrate having a surface and a coating of the rare earth-containing compound particles thermally sprayed to the substrate surface.

In the thermal spray particles of rare earth-containing compound according to the second embodiment of the present invention, their bulk density, cumulative pore

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volume and aspect ratio are controlled to the predetermined
ranges, their shape is made spherical, and optionally, their
particle size distribution is controlled to be sharp. Then
the particles generate few or no fines, remain free flowing,
5   have a high density and high strength, and completely melt
upon thermal spraying rather than collapsing. A coating
obtained by thermally spraying the particles has the
advantages of no dust deposition, smoothness, high purity,
improved bond, and corrosion resistance, as compared with
10   prior art sprayed coatings.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

First embodiment

In the first embodiment of the invention, spherical
15   particles for thermal spraying are formed of a rare
earth(inclusive of yttrium)-containing compound and have a
breaking strength of at least 10 MPa and an average particle
diameter of 10 to 80 μm.

As used herein, the "breaking strength" St is
20   determined from the following equation using as parameters a
particle diameter (d in mm) and a compression load (P)
measured by a micro-compression testing instrument Model
MCTM-500 (by Shimadzu Corp.).

25           $St = 2.8P/\pi d^2$

As used herein, the "average particle diameter" is a
diameter D50 corresponding to 50% by volume accumulation in
a particle size distribution as measured by a laser
30   diffraction analyzer. Fisher diameter is as measured by a
Fisher subsieve sizer.

As used herein, the term "rare earth" encompasses rare
earth elements of Group 3A in the Periodic Table inclusive
of yttrium (Y), that is, preferably Y, Eu, Gd, Tb, Dy, Ho,
35   Er, Tm, Yb, Lu, etc. The thermal spray spherical particles
of the invention are formed of a rare earth-containing
compound selected from the compounds of rare earth elements
of Group 3A inclusive of yttrium (Y). The "rare earth-

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containing compound" includes oxides, halides (fluorides, oxyfluorides, chlorides, etc.) and other compounds which contain rare earth elements. Especially, rare earth oxides are preferred. Of these oxides, yttrium oxide and ytterbium oxide are more preferred. It is understood that compound oxides of the rare earth combined with at least one metal selected from Al, Si, Zr, In, etc. are also useful for the inventive particles.

If the breaking strength St of thermal spray spherical particles is less than 10 MPa, the particles will collapse into fines in the flame or plasma during the spraying step. The upper limit of breaking strength is, though not critical, usually up to 300 MPa.

If the average particle diameter of thermal spray spherical particles is less than 10 μm, some particles may gasify during the spraying step, resulting in a reduced yield. If the average particle diameter is more than 80 μm, some particles may remain unmelted during the spraying step. The preferred average particle diameter is from 10 to 60 μm.

Of the thermal spraying spherical particles, the spherical particles of rare earth-containing compound are prepared by granulating rare earth-containing compound fines having a Fisher diameter of up to 0.6 μm into granules, and firing the granules at a temperature of 1,200 to 1,800°C.

If the Fisher diameter of rare earth-containing compound fines is more than 0.6 μm, the sintering of granules in the firing step is retarded, failing to produce spherical particles with a satisfactory breaking strength. With an improvement in breaking strength taken into account, the preferred Fisher diameter is 0.4 μm or less.

For granulation, any well-known technique may be employed. For example, granulation is carried out using a slurry of fines having a Fisher diameter of up to 0.6 μm in a suitable solvent. The solvent used to form the slurry is

not critical and may be selected from alcohols such as isopropanol, water and other solvents.

The resulting granules may have an appropriate size, and preferably an average particle diameter of 10 to 80 μm,
5   especially 10 to 60 μm because particles suited for thermal spraying are obtainable therefrom at the end of firing.

According to the inventive method, the firing step is carried out in an atmosphere of air, an inert gas or vacuum, using an electric furnace or the like. The firing
10 temperature is 1,200 to 1,800°C, more preferably 1,500 to 1,800°C when the rare earth oxide is used as the raw material. A firing temperature above the upper limit (1,800°C) might cause substantial fusion of particles, failing to obtain spherical particles.
15   More specifically, the thermal spray spherical particles are prepared by the procedure to be described below.

First, a slurry is prepared by adding a solvent such as water to a fine powder of rare earth-containing compound
20 having a Fisher diameter of up to 0.6 μm. Granules are then formed from the slurry using a granulator such as a tumbling granulator (i.e., rotary disk granulator), spray granulator, compression granulator or fluidized bed granulator. A granular powder having an average particle diameter of 10 to
25 80 μm is obtained.

By way of precaution for preventing the granules from being broken during collection or other operation, an organic material which will be burnt out in the firing step may be blended in the raw material oxide prior to
30 granulation. Examples of the organic material include polyvinyl alcohol (PVA), carboxymethyl cellulose (CMC), polyvinyl pyrrolidone (PVP), methyl cellulose (MC), hydroxypropyl cellulose (HPC), polyethylene glycol, phenolic resins, and epoxy resins. The amount of the organic
35 material added is not critical as long as it gives rise to no problem in the firing step. Usually, the organic

material is added in an amount of 0.1 to 5% by weight based
on the rare earth-containing compound fine powder.

In the granulation step by a granulator, more or less
non-spherical granules form. Since such non-spherical
5   granules can cause to reduce the flow of powder, it is
recommended to separate the granulated powder into non-
spherical granules and spherical granules by means of a
classifier, and to deliver only the spherical granule
fraction to the firing step.

10   The thus granulated powder is placed in a refractory
container and loaded in an electric furnace or the like in
which it is fired in an atmosphere of air, an inert gas or
vacuum at a temperature of 1,200-1,800°C for 5 min to 10 hr,
preferably 1 hr to 5 hr.

15   The firing step yields spherical particles which are
ready for use in thermal spraying. In the particles as
fired, however, some fusion bonds between particles are
usually found. If the particles in this partially fused
state are exposed to high-temperature plasma, melting is
20   insufficient on the coarse particle side, resulting in less
adhesion to the substrate. It is thus recommended to feed
the particles as fired to a disintegrator, pulverizer or
classifier (such as sieve), whereby fused particles are
separated into discrete monodisperse particles that are
25   thermal spray spherical particles with an average particle
diameter of 10 to 80 μm.

The thermal spray spherical particles obtained by the
above procedure have a sufficiently high breaking strength
of at least 10 MPa to withstand rupture during the spraying
30   step. Using the particles for thermal spraying, there is
obtained a sprayed coating in a sound state that unmelted
fines are not incorporated in the coating or do not stick to
the coating surface.

Second embodiment

35   In the second embodiment of the invention, spherical
particles for thermal spraying are formed of a rare earth-
containing compound and have a bulk density of at least 1.0

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g/cm^3, an aspect ratio of up to 2, and a cumulative volume of pores with a radius of up to 1 μm which is less than 0.5 cm^3/g.

As used herein, the "rare earth-containing compound" includes oxides, halides (fluorides, oxyfluorides and chlorides, etc.) and other compounds which contain rare earth elements. Of these, the oxides are preferred because they are vulnerable to sintering. In the following description, reference is made to oxide although the same discussion applies to other rare earth-containing compounds. Where the particles are of oxides, they preferably have a breaking strength of from 10 MPa to 300 MPa as in the first embodiment. The rare earth-containing oxide is selected from the oxides of rare earth elements of Group 3A inclusive of yttrium (Y) as in the first embodiment. Use is preferably made of a heavy rare earth-containing oxide that is an oxide containing at least one rare earth element selected from Y, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu. It is understood that compound oxides of the rare earth-containing oxide combined with at least one metal selected from Al, Si, Zr, In, etc. are also useful.

If the bulk density is less than 1.0 g/cm^3, particles are less dense and hence, rather weak, with a risk of collapsing upon spraying. The preferred bulk density is 1.2 to 5.0 g/cm^3.

If the cumulative pore volume is 0.5 cm^3/g or more, particles become more irregular on their surface, that is, smooth particles are not obtainable. In order that particles maintain relatively good fluidity even when their particle diameter is reduced, the cumulative volume of pores with a radius of up to 1 μm should be less than 0.5 cm^3/g. Preferably the cumulative volume of pores with a radius of up to 1 μm is 0.3 cm^3/g or less because the particles are better flowing. The pore radius and the cumulative pore volume can be measured by Mercury Porosity-metry.

The thermal spray particles of rare earth-containing compound according to the invention are spherical in shape. Namely, the particles have an aspect ratio of up to 2. As used herein, the "aspect ratio" is defined as the ratio of major diameter to minor diameter of a particle, that is an index indicating whether the particle shape is approximate to sphere. An aspect ratio of more than 2 indicates that particles have an irregular, needle, flaky or other shape dissimilar from sphere, leading to disturbed flow. The lower limit of the aspect ratio is, though not critical, preferably close to 1. The term "spherical" as used herein means the shape of particles having an aspect ratio of up to 2 and thus embraces true spherical to generally spherical shapes.

In the second embodiment of the invention, the particles have a particle size distribution in which a particle diameter D90, D50 and D10 corresponds to 90 vol%, 50 vol% and 10 vol% accumulation, respectively. In a preferred embodiment, D90 is up to 50 μm and the ratio of D50 to a Fisher diameter is up to 5.

If the particle diameter D90 exceeds 100 μm, there is a risk that particles are not completely melted in the plasma flame and thus form non-fused particles, and irregularities occur on the coating surface.

If the ratio of D50/Fisher diameter exceeds 5, there are contained more fractions of coarse particles and fines, which preclude precise feed at a constant rate. If the ratio of D50/Fisher diameter is up to 5, preferably between 1 and 3, the powder is judged to contain less fractions of coarse particles and fines. As pores open at particle surfaces become smaller, the ratio of D50/Fisher diameter becomes smaller, which enables constant feed. Even when the particle diameter is further reduced, precise feed at a constant rate is possible. As a consequence, using the thermal spray particles in this preferred embodiment, a smooth, dense sprayed coating can be formed.

As previously defined, Fisher diameter is as measured by a Fisher subsieve sizer. More specifically, the Fisher diameter is calculated from a difference in gas pressure across a powder bed through which gas passes, and thus dependent on the average particle diameter and particle size distribution of the powder and the surface state of particles. Then, in the case of a large average particle diameter, a sharp particle size distribution and/or a smooth particle surface, the Fisher diameter is calculated to be relatively large. Accordingly, when the ratio of D50/Fisher diameter is calculated, a lower ratio suggests a sharper particle size distribution or a smoother particle surface. Particularly, at the same particle size distribution, particles with a lower D50/Fisher diameter ratio are judged to have a smoother surface.

In a further preferred embodiment, D10 is at least 5 μm, and the particles having a dispersion index of up to 0.6. This setting leads to suppressed generation of fines, a sharp particle size distribution, and improved particle flow, and precludes clogging of a nozzle through which the powder is fed. It is noted that the dispersion index is defined as:

Dispersion index = (D90-D10)/(D90+D10).

The particles are further improved in flow when they are controlled so as to have a dispersion index of 0.1 to 0.5 and an angle of repose of up to 44°.

In a still further preferred embodiment, the thermal spray particles of rare earth-containing compound have a specific surface area of up to 2.0 m^2/g, and more preferably 0.1 to 1.5 m^2/g. A surface area in excess of 2.0 m^2/g invites a likelihood that particles become collapsible, causing dust generation.

When it is desired that a coating formed on a component by spraying the particles be of high purity and free of colored spots, and impart satisfactory corrosion resistance to the coated component. The thermal spray

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particles of rare earth-containing compound should preferably have a limited impurity content. First, the content of each of iron group elements (Fe, Ni, Co, etc.), alkali metal elements (Na, K, etc.) and alkaline earth metal elements (Mg, Ca, etc.) in the particles should preferably be up to 5 ppm, calculated as oxide. The lower the content of these metal elements, the better are the results. In most cases, the lower limit is about 0.1 ppm. It is noted that the content of iron group elements, alkali metal elements or alkaline earth metal elements is measured by inductively coupled plasma (ICP) emission spectrometry after acidolysis of the particles.

Secondly, the content of carbon in the thermal spray particles should preferably be up to 100 ppm. A limited carbon content below 100 ppm prevents the bond between particles in the sprayed coating from being weakened by residual carbon, and hence, precludes dust generation. This indicates that even when granules are formed from a starting powder material using a binder, they are preferably fired so as to minimize the residual carbon, thereby preventing formation of carbide with the starting material.

For polycrystalline particles, it is believed that they are more dense as single crystal grains constituting each particle have a larger grain size. The single crystal grains constituting each particle are generally known as crystallites. In the thermal spray particles of rare earth-containing compound according to the invention, the crystallites preferably have a size of at least 25 nm, and more preferably at least 50 nm. When the crystallite size is less than 25 nm, polycrystalline particles with such a small single crystal grain size are not regarded dense in many cases. Note that the crystallite size is determined by effecting x-ray diffraction analysis and calculating according to Wilson method. According to Wilson method, the crystallite size is normalized to fall in the range of 0 to 100 nm, regardless of the actual size of single crystal grains.

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The thermal spray particles of rare earth-containing oxide are prepared, for example, by the procedure to be described below.

First, a slurry is prepared by adding fines of rare earth-containing compound, especially rare earth-containing oxide having a Fisher diameter of up to 0.6 μm and an average particle diameter (primary particle) of 0.01 to 5 μm, preferably 0.01 to 1 μm to a medium such as water or alcohol along with a binder. Granulation from the slurry is then carried out using a granulator such as a tumbling granulator, spray granulator, compression granulator or fluidized bed granulator. The granules are dried and fired in air or inert gas atmosphere or under vacuum at 1,200 to 1,800°C, preferably 1,500 to 1,800°C for 5 min to 10 hr, preferably 1 hr to 5 hr, yielding free flowing particles having a particle diameter D90 of up to 100 μm, a D50/Fisher diameter ratio of up to 5, a bulk density of at least 1.0 g/cm^3, a cumulative pore volume of less than 0.5 cm^3/g, an aspect ratio of up to 2, and a generally spherical shape.

Examples of the binder include polyvinyl alcohol (PVA), celluloses such as carboxymethyl cellulose (CMC), hydroxypropyl cellulose (HPC) and methyl cellulose (MC), polyvinyl pyrrolidone (PVP), polyethylene glycol (PEG), polytetrafluoroethylene (PTFE), phenolic resins, and epoxy resins. Usually, the binder is added in an amount of 0.1 to 5% by weight based on the rare earth-containing compound.

The thermal spray particles of rare earth-containing compound are generally spherical and relatively small in shape, contain a minimal amount of fines, and have less irregular, smooth surfaces. The particles are thus smoothly flowing and ensure precise metering to a spray nozzle without causing clogging thereof. As a result, a coating obtained by spraying the particles is smooth, dense and substantially free of sticking fines.

In a further embodiment, the invention provides a thermally sprayed component comprising a substrate and a

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coating of the rare earth-containing compound particles
thermally sprayed to a surface of the substrate.

The material of the substrate is usually selected from
metals, alloys, ceramics and glass, though not limited
thereto. Examples include Al, Ni, Cr, Zn, Zr, Si and
alloys, oxides, nitrides and carbides thereof such as
alumina, aluminum nitride, silicon nitride, silicon carbide,
quartz glass, and zirconia.

The coating on the substrate surface preferably has a
thickness of 50 to 500 μm, more preferably 150 to 300 μm. A
coating thickness of less than 50 μm leads to a likelihood
that the sprayed component, on use as a corrosion resistant
component, must be replaced by a new one just after faint
corrosion. A coating of more than 500 μm thick is too thick
and has a risk that delamination occurs within it.

The coating preferably has a surface roughness of up
to 60 μm, more preferably up to 40 μm. A surface roughness
of more than 60 μm might have a risk of dusting during the
service of the sprayed component and presents a larger
plasma contact area which may degrade corrosion resistance
and allow fines to generate with the progress of corrosion.
Namely, a coating having a surface roughness of up to 60 μm
ensures good corrosion resistance and minimizes the sticking
of fines to the coating surface. It is then effective for
precluding corrosion even in a corrosive gas atmosphere as
typified by halide gas plasma. Then the sprayed component
is advantageously used as a corrosion resistant component.
Since the spray particles of rare earth-containing compound
are used, the sprayed component is minimized in dusting as
demonstrated by a population of sticking non-fused particles
on the coating surface being up to 10 particles/100 μm².

The spray coated component of the invention is
obtainable by plasma or vacuum spraying the rare earth-
containing compound particles to the substrate surface to
form a coating thereon. The plasma gas used herein is

usually selected from nitrogen/hydrogen, argon/hydrogen, argon/helium and argon/nitrogen, though not limited thereto. The spraying conditions are not critical and may be determined as appropriate in accordance with the type of
5   substrate and rare earth-containing compound particles used and the desired application of the spray coated component.

     In the spray coated component, the coating should preferably have a limited content of iron group elements, alkali metal elements and alkaline earth metal elements
10   which is each up to 5 ppm, calculated as oxide. This level is accomplished using spray particles of rare earth-containing compound having a limited metal element content of up to 5 ppm as described above. Differently stated, when coating is formed using spray particles of rare earth-
15   containing compound having iron group elements, alkali metal elements and alkaline earth metal elements introduced each at a content of more than 5 ppm, the iron group elements, alkali metal elements and alkaline earth metal elements are incorporated in the coating in the same content as in the
20   starting spray particles, which might exert detrimental effects on wafers when the spray coated component is used in semiconductor equipment.

     As mentioned above, the sprayed component of the invention bears a smooth, dense coating having a surface
25   roughness of up to 60 µm and a high purity as demonstrated by a limited content of iron group elements, alkali metal elements and alkaline earth metal elements which is each 5 ppm or less, calculated as oxide. Then the sprayed component can be used in equipment where a high purity is
30   crucial, because the sprayed component generates less fines or dust during plasma etching so that the introduction of impurities into wafers being processed is minimized. More specifically, the sprayed component is best suited for use in liquid crystal manufacturing equipment and semiconductor
35   manufacturing equipment, to name a few.

EXAMPLE

Examples of the invention are given below by way of illustration and not by way of limitation.

5   Example 1

10 g of methyl cellulose was added to 5 kg of yttrium oxide having a Fisher diameter of 0.45 μm, to which deionized water was added to give an approximately 40 wt% aqueous slurry. The aqueous slurry was sprayed by a spray
10   dryer, forming granules having an average particle diameter of about 50 μm.

The granule powder was fired in an electric furnace having an air atmosphere at 1,600° C for 2 hours and cooled. The thus obtained powder was passed through a sieve with an
15   opening of 150 μm, obtaining a thermal spray powder of spherical particles having an average particle diameter of 50 μm. The particles had a breaking strength of about 13 MPa, when measured using a planar indenter at a testing load of 980 mN and a load applying rate of about 41.5 mN/sec.
20

Example 2

Thermal spray spherical particles having an average particle diameter of 50 μm were prepared as in Example 1 except that yttrium oxide having a Fisher diameter of 0.28
25   μm was used. The particles were measured to have a breaking strength of about 160 MPa.

Example 3

Thermal spray spherical particles having an average
30   particle diameter of 49 μm were prepared as in Example 1 except that yttrium oxide having a Fisher diameter of 0.35 μm was used. The particles were measured to have a breaking strength of about 130 MPa.

Example 4

     Thermal spray spherical particles having an average particle diameter of 50 μm were prepared as in Example 1 except that ytterbium oxide having a Fisher diameter of 0.28 μm was used. The particles were measured to have a breaking strength of about 160 MPa.

Example 5

     Thermal spray spherical particles having an average particle diameter of 50 μm were prepared as in Example 1 except that ytterbium oxide having a Fisher diameter of 0.30 μm was used. The particles were measured to have a breaking strength of about 120 MPa.

Comparative Example 1

     Thermal spray spherical particles having an average particle diameter of 50 μm were prepared as in Example 1 except that yttrium oxide having a Fisher diameter of 1.5 μm was used. The particles were measured to have a breaking strength of about 2 MPa.

     Table 1 summarizes the type and Fisher diameter of the starting powder, the firing temperature, and the average particle diameter and breaking strength of thermal spray spherical particles in the foregoing Examples and Comparative Examples.

Table 1

		Starting powder		Firing temperature (°C)	Spray particles	
		Type	Fisher diameter (μm)		Average particle diameter (μm)	Breaking strength (MPa)
Example	1	yttrium oxide	0.45	1600	50	13
	2	yttrium oxide	0.28	1600	50	160
	3	yttrium oxide	0.35	1600	49	130
	4	ytterbium oxide	0.28	1600	50	160
	5	ytterbium oxide	0.30	1600	50	120
Comparative Example	1	yttrium oxide	1.5	1600	50	2

As seen from the results of Examples and Comparative Examples, spray spherical particles prepared using a starting oxide powder having a Fisher diameter of less than 0.6 μm had a breaking strength of more than 10 MPa and sometimes (in Examples 2-5) more than 50 MPa.

Using a plasma spraying torch, the spray particles obtained in Examples and Comparative Examples were sprayed to alumina ceramic substrates. When the spray particles having a breaking strength of more than 10 MPa in Examples were used, no fines resulting from rupture of particles developed during the spraying and good sprayed coatings were obtained.

Since the thermal spray spherical particles in the first embodiment of the invention are formed of rare earth oxide and have a breaking strength of at least 10 MPa and an average particle diameter of 10 to 80 μm according to the present invention, they do not collapse into fines in the spraying flame or plasma. By spraying the particles, there is formed a satisfactory coating having no fines stuck to its surface.

Example 6

  In 12 liters of deionized water was dissolved 15 g of
polyvinyl alcohol (PVA). 8 kg of yttrium oxide having a
Fisher diameter of 0.5 µm and containing less than 0.5 ppm
5 of Fe_2O_3 was dispersed therein to form a slurry. Using a
spray granulator, the slurry was spray dried to form
spherical granules. The granulated powder was fired in air
at 1,600°C for 2 hours, obtaining spherical particles for
thermal spraying.

10 The spray particles obtained by the above procedure
were measured for diameter using a laser diffraction
particle size meter, finding a D90 of 45 µm. The particles
had a bulk density of 1.86 g/cm³, a specific surface area of
0.6 m²/g as measured by the BET method, a cumulative volume
15 of pores with a radius of up to 1 µm which was 0.18 cm³/g,
an average particle diameter D50/Fisher diameter ratio of
2.25, and an aspect ratio of 1.01. Note that the cumulative
pore volume was measured by a mercury penetration
auto-scanning porosimeter Model 33 by Yuasa Ionics K.K.

20 The particles were measured for impurity concentration
by ICP emission spectrometry after acidolysis, finding 1 ppm
of Fe_2O_3 and 2 ppm of CaO. On atomic-absorption spectroscopy
analysis, the particles contained 5 ppm of Na_2O and 70 ppm
of carbon.

25 Using an argon/hydrogen gas plasma, the particles were
sprayed to an aluminum alloy substrate (No. 6061 defined in
JIS H4000) to form a coating of 190 µm thick thereon.
During the spraying step, the nozzle was not clogged at all.
The coating was measured for surface roughness as an
30 indicator of smoothness, finding a Rmax of 48 µm according
to JIS B0601.

  For examining the denseness, the sprayed coating was
measured for relative density. After the spray coated
substrate was dipped in dilute hydrochloric acid, and the
35 coating was stripped from the substrate, the relative

density was measured by Archimedes method. A relative
density of 92% was recorded.

Example 7
5   In 16 liters of deionized water was dissolved 15 g of
carboxymethyl cellulose (CMC). 4 kg of ytterbium oxide
having a Fisher diameter of 0.4 μm and containing less than
0.5 ppm of Fe_2O_3 was dispersed therein to form a slurry.
Using a spray granulator, the slurry was spray dried to form
10   spherical granules. The granulated powder was fired in air
at 1,500°C for 2 hours, obtaining spherical particles for
thermal spraying.
        The spray particles obtained by the above procedure
were measured for diameter using a laser diffraction
15   particle size meter, finding a D90 of 36 μm. The particles
had a bulk density of 2.2 g/cm^3, a BET specific surface area
of 0.5 m^2/g, a cumulative pore volume (pore radius ≤ 1 μm) of
0.04 cm^3/g, a D50/Fisher diameter ratio of 2.05, and an
aspect ratio of 1.02.
20   The particles were measured for impurity concentration
by ICP emission spectrometry after acidolysis, finding 1 ppm
of Fe_2O_3 and 3 ppm of CaO. Atomic-absorption spectroscopy
showed a Na_2O content of 4 ppm and a carbon concentration of
60 ppm.
25   Using an argon/hydrogen gas plasma, the particles were
sprayed to an aluminum alloy substrate to form a coating of
210 μm thick thereon. During the spraying step, the nozzle
was not clogged at all. The coating was measured for
surface roughness, finding a Rmax of 39 μm.
30   For examining the denseness, the sprayed coating was
measured for relative density as in Example 6. A relative
density of 90% was recorded.

Example 8
35   In 18 liters of deionized water was dissolved 30 g of
polyethylene oxide (PEO). 2 kg of yttrium oxide having a

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Fisher diameter of 0.3 μm and containing less than 0.5 ppm
of Fe_2O_3 was dispersed therein to form a slurry. Using a
spray granulator, the slurry was spray dried to form
spherical granules. The granulated powder was fired in air
5   at 1,650°C for 2 hours, obtaining spherical particles for
thermal spraying.

The spray particles obtained by the above procedure
were measured for diameter using a laser diffraction
particle size meter, finding a D90 of 28 μm. The particles
10   had a bulk density of 1.6 g/cm^3, a BET specific surface area
of 0.7 m^2/g, a cumulative pore volume (pore radius ≤ 1 μm) of
0.04 cm^3/g, a D50/Fisher diameter ratio of 2.13, and an
aspect ratio of 1.01.

The particles were measured for impurity concentration
15   by ICP emission spectrometry after acidolysis, finding 3 ppm
of Fe_2O_3 and 3 ppm of CaO. Atomic-absorption spectroscopy
showed a Na_2O content of 4 ppm and a carbon concentration of
60 ppm.

Using an argon/hydrogen gas plasma, the particles were
20   vacuum sprayed to a silicon substrate to form a coating of
200 μm thick thereon. During the spraying step, the nozzle
was not clogged at all. The coating was measured for
surface roughness, finding a Rmax of 26 μm.

For examining the denseness, the sprayed coating was
25   measured for relative density as in Example 6. A relative
density of 91% was recorded.

Example 9

In 12 liters of deionized water was dissolved 15 g of
30   polyvinyl alcohol (PVA). 8 kg of yttrium oxide having a
Fisher diameter of 0.6 μm and containing less than 0.5 ppm
of Fe_2O_3 was dispersed therein to form a slurry. Using a
spray granulator, the slurry was spray dried to form
spherical granules. The granulated powder was fired in air
35   at 1,600°C for 2 hours. After fines were removed by a

classifier, there were obtained spherical particles for thermal spraying.

The spray particles obtained by the above procedure were measured for diameter using a laser diffraction particle size meter, finding a D90 of 39 μm, a D10 of 23 μm and a dispersion index of 0.25. The particles had an aspect ratio of 1.02, a bulk density of 1.5 g/cm^3, a cumulative pore volume (pore radius ≤ 1 μm) of 0.19 cm^3/g, and an angle of repose of 38°.

The particles were measured for impurity concentration by ICP emission spectrometry after acidolysis, finding 1 ppm of Fe_2O_3 and 2 ppm of CaO. Atomic-absorption spectroscopy showed a Na_2O content of 5 ppm and a carbon concentration of 70 ppm.

Using an argon/hydrogen gas plasma, the particles were sprayed to an aluminum alloy substrate to form a coating of 190 μm thick thereon. During the spraying step, the nozzle was not clogged at all.

The surface of the sprayed component was observed under an electron microscope. In the photomicrograph, the number of sticking unmelted particles of a size of less than 5 μm in a 100 μm square area was counted, finding 5 particles.

Example 10

In 16 liters of deionized water was dissolved 15 g of polyethylene oxide (PEO). 4 kg of ytterbium oxide having a Fisher diameter of 0.4 μm and containing less than 0.5 ppm of Fe_2O_3 was dispersed therein to form a slurry. Using a spray granulator, the slurry was spray dried to form spherical granules. The granulated powder was fired in air at 1,500°C for 2 hours. After fines were removed by a classifier, there were obtained spherical particles for thermal spraying.

The spray particles obtained by the above procedure were measured for diameter using a laser diffraction

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particle size meter, finding a D90 of 37 μm, a D10 of 16 μm and a dispersion index of 0.40. The particles had an aspect ratio of 1.01, a bulk density of 1.8 g/cm³, a cumulative pore volume (pore radius ≤ 1 μm) of 0.04 cm³/g, and an angle of repose of 40°.

The particles were measured for impurity concentration by ICP emission spectrometry after acidolysis, finding 1 ppm of Fe_2O_3 and 3 ppm of CaO. Atomic-absorption spectroscopy showed a Na_2O content of 4 ppm and a carbon concentration of 70 ppm.

Using an argon/hydrogen gas plasma, the particles were sprayed to an aluminum alloy substrate to form a coating of 210 μm thick thereon. During the spraying step, the nozzle was not clogged at all.

The surface of the sprayed component was observed under an electron microscope. The number of sticking unmelted particles of a size of less than 5 μm in a 100 μm square area was 3.

Example 11

In 18 liters of deionized water was dissolved 15 g of methyl cellulose (MC). 2 kg of yttrium oxide having a Fisher diameter of 0.3 μm and containing less than 0.5 ppm of Fe_2O_3 was dispersed therein to form a slurry. Using a spray granulator, the slurry was spray dried to form spherical granules. The granulated powder was fired in air at 1,500°C for 2 hours. After fines were removed by a classifier, there were obtained spherical particles for thermal spraying.

The spray particles obtained by the above procedure were measured for diameter using a laser diffraction particle size meter, finding a D90 of 34 μm, a D10 of 16 μm and a dispersion index of 0.36. The particles had an aspect ratio of 1.01, a bulk density of 2.2 g/cm³, a cumulative

pore volume (pore radius ≤ 1 μm) of 0.03 cm³/g, and an angle of repose of 42°.

The particles were measured for impurity concentration by ICP emission spectrometry after acidolysis, finding 3 ppm of Fe_2O_3 and 3 ppm of CaO. Atomic-absorption spectroscopy showed a Na_2O content of 4 ppm and a carbon concentration of 50 ppm.

Using an argon/hydrogen gas plasma, the particles were sprayed to quartz substrate to form a coating of 200 μm thick thereon. During the spraying step, the nozzle was not clogged at all.

The surface of the sprayed component was observed under an electron microscope. The number of sticking unmelted particles of a size of less than 5 μm in a 100 μm square area was 2.

Example 12

In 18 liters of deionized water was dissolved 15 g of polyvinyl alcohol (PVA). 2 kg of yttrium aluminum garnet having a Fisher diameter of 0.6 μm was dispersed therein to form a slurry. Using a granulator, granules were formed from the slurry. They were dried and fired in an electric furnace at 1,500°C for 2 hours. After fines were removed by a classifier, there were obtained spherical particles for thermal spraying.

The spray particles obtained by the above procedure were measured for diameter using a laser diffraction particle size meter, finding a D90 of 36 μm, a D10 of 15 μm and a dispersion index of 0.41. The particles had an aspect ratio of 1.06, a bulk density of 1.1 g/cm³, and a cumulative pore volume (pore radius ≤ 1 μm) of 0.3 cm³/g.

The particles were measured for impurity concentration by ICP emission spectrometry after acidolysis, finding 4 ppm of Fe_2O_3 and 4 ppm of CaO. Atomic-absorption spectroscopy showed a Na_2O content of 5 ppm and a carbon concentration of 65 ppm.

Using an argon/hydrogen gas plasma, the particles were sprayed to an aluminum alloy substrate to form a coating of 203 μm thick thereon. During the spraying step, the nozzle was not clogged at all.

The surface of the sprayed component was observed under an electron microscope. The number of sticking unmelted particles of a size of less than 5 μm in a 100 μm square area was 2.

Example 13

In 18 liters of deionized water was dissolved 15 g of polyvinyl alcohol (PVA). 2 kg of ytterbium silicate having a Fisher diameter of 0.6 μm was dispersed therein to form a slurry. Using a granulator, granules were formed from the slurry. They were dried and fired in an electric furnace at 1,500° C for 2 hours. After fines were removed by a classifier, there were obtained spherical particles for thermal spraying.

The spray particles obtained by the above procedure were measured for diameter using a laser diffraction particle size meter, finding a D90 of 33 μm, a D10 of 14 μm and a dispersion index of 0.40. The particles had an aspect ratio of 1.1, a bulk density of 1.9 g/cm^3, and a cumulative pore volume (pore radius ≤ 1 μm) of 0.28 cm^3/g.

The particles were measured for impurity concentration by ICP emission spectrometry after acidolysis, finding 3 ppm of Fe_2O_3 and 5 ppm of CaO. Atomic-absorption spectroscopy showed a Na_2O content of 4 ppm and a carbon concentration of 72 ppm.

Using an argon/hydrogen gas plasma, the particles were sprayed to an aluminum alloy substrate to form a coating of 194 μm thick thereon. During the spraying step, the nozzle was not clogged at all.

The surface of the sprayed component was observed under an electron microscope. The number of sticking

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unmelted particles of a size of less than 5 μm in a 100 μm square area was 3.

Comparative Example 2

In 12 liters of deionized water was dissolved 15 g of polyvinyl alcohol (PVA). 8 kg of yttrium oxide having a Fisher diameter of 1.1 μm and containing less than 0.5 ppm of Fe_2O_3 was dispersed therein to form a slurry. Using a spray granulator, the slurry was spray dried to form spherical granules. They were fired in air at 1,600°C for 2 hours, obtaining spherical particles for thermal spraying.

The spray particles obtained by the above procedure were measured for diameter using a laser diffraction particle size meter, finding a D90 of 106 μm. The particles had a bulk density of 1.1 g/cm^3, a BET specific surface area of 1.4 m^2/g, a cumulative pore volume (pore radius ≤ 1 μm) of 0.55 cm^3/g, a D50/Fisher diameter ratio of 6.93, and an aspect ratio of 1.1.

The particles were measured for impurity concentration by ICP emission spectrometry after acidolysis, finding 3 ppm of Fe_2O_3 and 2 ppm of CaO. Atomic-absorption spectroscopy showed a Na_2O content of 5 ppm and a carbon concentration of 80 ppm.

Using an argon/hydrogen gas plasma, the particles were sprayed to an aluminum alloy substrate to form a coating of 195 μm thick thereon. During the spraying step, the nozzle was not clogged at all. The coating was measured for surface roughness, finding a Rmax of 88 μm.

For examining the denseness, the sprayed coating was measured for relative density as in Example 6. A relative density of 84% was recorded.

Comparative Example 3

Yttrium oxide having a Fisher diameter of 4 μm, 3 kg, was melted and solidified. This was followed by grinding

and classification, obtaining spherical particles for thermal spraying.

The spray particles obtained by the above procedure were measured for diameter using a laser diffraction particle size meter, finding a D90 of 110 μm. The particles had a bulk density of 2.1 g/cm^3, a BET specific surface area of 0.1 m^2/g, a cumulative pore volume (pore radius ≤ 1 μm) of up to 0.01 cm^3/g, a D50/Fisher diameter ratio of 3.05, and an aspect ratio of 2.6.

The particles were measured for impurity concentration by ICP emission spectrometry after acidolysis, finding 55 ppm of Fe_2O_3 and 40 ppm of CaO. Atomic-absorption spectroscopy showed a Na_2O content of 10 ppm and a carbon concentration of 92 ppm.

Using an argon/hydrogen gas plasma, the particles were sprayed to an aluminum alloy substrate to form a coating of 190 μm thick thereon. During the spraying step, the nozzle was not clogged at all. The coating was measured for surface roughness, finding a Rmax of 94 μm.

For examining the denseness, the sprayed coating was measured for relative density as in Example 6. A relative density of 91% was recorded.

All the spray particles of rare earth-containing oxide obtained in Examples 6-8 have a D90 of up to 100 μm in particle size distribution, a D50/Fisher diameter ratio of up to 5, a bulk density of at least 1.0 g/cm^3, a cumulative pore volume (pore radius ≤ 1 μm) of less than 0.5 cm^3/g, and a generally spherical shape with an aspect ratio of up to 2. In addition, the impurity contents are low as demonstrated by a Fe_2O_3, CaO and Na_2O content of each up to 5 ppm.

Using these particles, a sprayed coating of high purity is formed. The coating has a high density and a smooth surface and is strippable with difficulty. When the sprayed component is used in semiconductor manufacturing process, the generation of dust from the sprayed component is minimized. The sprayed component is advantageously used

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in the application where a high purity is required, for example, liquid crystal manufacturing equipment and semiconductor manufacturing equipment.

The sprayed component has a smooth coating with a surface roughness of up to 60 μm and is useful as a corrosion resistant component for operation in a corrosive gas atmosphere such as halide gas plasma.

The spray particles of rare earth-containing oxide obtained in Examples 9-13 enable precise metering despite their smaller particle diameter and have a cumulative pore volume (pore radius ≤ 1 μm) of less than 0.5 cm³/g, an aspect ratio of up to 2, a bulk density of at least 1.0 g/cm³, and a particle size distribution with a D10 of at least 10 μm, a D90 of up to 100 μm, and a dispersion index of up to 0.6. In addition, they are highly pure in that the impurity contents are as low as a Fe_2O_3, CaO and Na_2O content of each up to 5 ppm.

Using these particles, a sprayed coating of high purity is formed. Since the number of sticking unmelted particles with a size of less than 5 μm in a 100 μm square area is up to 10, the sprayed component, when used in semiconductor manufacturing process, minimizes the generation of dust therefrom. The sprayed component is advantageously used in the application where a high purity is required, for example, liquid crystal manufacturing equipment and semiconductor manufacturing equipment.

The sprayed component has a smooth coating with a reduced surface roughness and is useful as a corrosion resistant component for operation in a corrosive gas atmosphere such as halide gas plasma.

In contrast, the spray particles of Comparative Example 2 have a D90 as large as 106 μm and a D50/Fisher diameter ratio of 6.93. As a result, a coating obtained by spraying the particles has a large surface roughness and fails to suppress dust generation in the semiconductor manufacturing process.

The spray particles of Comparative Example 3 have a D50/Fisher diameter ratio as small as 3.05 and provide a coating having a high relative density. However, the iron group element, alkali metal element and alkaline earth metal element are present in the coating in the amounts corresponding to those in the spray particles. When the sprayed component is used in the semiconductor manufacturing process, these impurities can contaminate silicon wafers and become process disturbances. The sprayed component is unsuited in the semiconductor manufacturing equipment and similar application where a high purity is required.

The sprayed component has a rough coating with a surface roughness of 69 μm and allows dust to generate in the semiconductor manufacturing process, which dust undesirably causes to contaminate silicon wafers.

The thermal spray particles of rare earth-containing compound according to the second embodiment of the present invention have a bulk density of at least 1.0 g/cm^3, an aspect ratio of up to 2, a cumulative pore volume (pore radius ≤ 1 μm) of less than 0.5 cm^3/g and a generally spherical shape. The particles are thus smoothly flowing and can be precisely fed at a constant rate to a spray nozzle without causing clogging. A coating obtained by spraying the particles is smooth and dense.

Japanese Patent Application Nos. 2001-064725 and 2001-109182 are incorporated herein by reference.

Reasonable modifications and variations are possible from the foregoing disclosure without departing from either the spirit or scope of the present invention as defined by the claims.